ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

PROJECT NO. 20 - STUDIES OF COLD WEATHER CLOTHING

Report On

Sub-Project 20-1, The Effect of Leakage from Closures Upon Thermal Protection (OQMG Test Number 57 I-A).

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Project No. 20-1

14 June 1944

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project 20-1 (OQMG 57 I-A)
727-1 SPMEA

14 June 1944

1. PROJECT NO. 20 - Studies of Cold Weather Clothing. Report on Sub-Project 20-1 - The Effect of Leakage from Closures Upon Thermal Protection (OQMG Test Number 57 I-A).

a. Authority - 2nd Indorsement, Commanding General, Army Ground Forces, file 450 (21 Jan 44) GNRQT-11/69428.

b. Purpose - (1) To evaluate the relative importance of leakage of air through closures and (2) to determine the best means of providing adequate ventilation of clothing during work without decreasing the thermal efficiency of the garments when at rest.

2. DISCUSSION:

a. It is doubtful if the provision of anything beyond reasonably adequate closures on garments for Arctic wear will have any significant influence upon the thermal protection afforded by such garments under standard resting conditions. There are other avenues of heat leakage from the individual of much greater importance, viz--extremities and face, which, owing to the difficulty of providing adequate insulation for them, may be responsible for up to fifty (50) per cent of the total heat loss.

b. There is, however, the practical problem of providing for convenient ventilation of garments so that excessive sweating during and immediately after work can be avoided or minimized. With present Arctic issues the wearer must remove outer garments to insure ventilation and otherwise offset the extra heat production during active work. Removal and replacement of garments under combat conditions is not only impractical but unlikely. One method for insuring ease of ventilation is to provide openings in the garments which may be effectively closed when required. If garments are so altered, it is important to know if the thermal protection afforded by the garment to the resting man has been appreciably reduced. These tests have been primarily concerned, therefore, with determining (1) the adequacy of modified garment combinations in preventing accumulation of sweat during work and (2) the thermal exchanges through these garment combinations at rest.

3. CONCLUSIONS:

a. The substitution of a fly-front parka windbreak and fly-front pile parka for the standard closed-front parkas does not reduce the thermal protection of the garments for a seated man, as measured by present techniques.

b. The use of the front-opening outer garments is extremely helpful in providing ventilation during work.

c. Complete sealing of all closures in the outer windbreak garments with similar material does not result in any significant improvement in the thermal behavior of the combination.

4. RECOMMENDATIONS:

a. That the zipper fly-front 9 ounce sateen parka and zipper fly-front pile parka be considered for adoption to replace the present standard non-opening items.

b. That the present garment closures do not need to be improved.

Submitted by:
Steven M. Horvath, Captain, SnC
John E. Wagar, Tec 3
Howard Golden, Tec 3

APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps
Commanding

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APPENDIX

I. EXPERIMENTAL METHODS

a. The methods employed for the study of thermal exchange in man were like those previously described. Skin temperatures, rectal temperatures and metabolism were measured on subjects seated in the wind tunnel with wind velocities of zero (0), five (5.0) and nine and six-tenths (9.6) miles per hour. Subjective responses were obtained, following our standard procedure.

b. The men walked on a motor driven treadmill with a three per cent grade at a speed of 3.3 miles per hour. The nude men and their clothing were weighed before and after a walk of one or two hours duration. The weighing and dressing took place in a small chamber within the cold room, the temperature of which was above 0°F and below 32°F. The clothes were kept and weighed in water-proof bags. Rectal temperatures were taken immediately before and after each hour's walk. Three main types of walking experiments were performed: (a) no ventilation--the men wearing their clothes completely closed at all times; (b) ventilation permitted as allowed by the garments--the men opening up as much as possible without removing any garments and (c) complete ventilation--the men removing garments as necessary to prevent themselves from becoming overheated. In this last experiment the time at which the garment was removed was noted and the garment immediately placed into a waterproof bag.

c. In a number of cases the men, after walking, proceeded to sit for several hours and standard observations were made.

II. TEST CLOTHING

Below is listed most of the clothing that was used. Additional modifications will be mentioned in the text, where required.

Control Clothing worn by subjects in these tests-

Drawers, Wool, 50/50
Undershirt, Wool, 50/50
Shirt, Flannel, O.D.
Trousers, Field, Pile
Trousers, Field, Cotton, O.D., Sateen, 9 oz.
Parka, Field, Cotton, O.D., Sateen, 9 oz.
Parka, Pile
Shoe, Arctic Felt
Socks, Wool, Ski (2 pair)
Socks, Wool, cushion (1 pair)
Mittens, Insert, Trigger Finger M-1943
Mittens, Shell, Trigger Finger M-1943
Mufflers, Wool
Wristlets, Knit

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Experimental Clothing -

a. A fly-front parka with as draught-proof a front closure as could be designed (Fig. 1).

b. A standard Arctic assembly with closures made as tight as possible (Fig. 2). (Outer windproof garments of 9 oz. sateen with an air permeability of 5.0 cfm/sq.ft.).

c. Experimental parka (see a, above) plus parka pile, with front zipper opening (Fig. 3). Several styles were used. In one garment, the opening was only partial while in another it was complete from neck to hem.

d. The following items were worn in the exercise experiments only:

(1) Napped outer windproof garments and napped pile garments.

(2) Windproof garments.

(a) Nylon - air permeability of zero (0) cfm/sq.ft.
(b) Khaki twill, 8.2 oz. - air permeability of 10 cfm/sq.ft.
(c) Herringbone twill - air permeability of 20 cfm/sq.ft.

e. Pile garments made of 50/50 alpaca-mohair but with the length of the pile increased to 5/8 inch instead of the 1/2 inch length in the standard garments.

III. RESULTS

a. Thermal Protection for Resting Subjects

In order to furnish some evidence of the insulation value of the several combinations under test, clo values calculated from the predicted equilibrium temperature θ_e, are given in Table 1. These data are presented only for the purpose of showing that, within the limits of accuracy and usefulness of the index thus calculated, there is no alteration in insulation among the various combinations studied. The values presented are averages for two (2) or three (3) subjects except in the case of tests on the double windproof where only one subject was available. It will be noted that no data for zero wind velocities are presented. For comparison, however, studies at zero wind on two subjects wearing the zipper front parkas gave clo values of 4.7 and 5.3. Mean skin temperatures are shown for Subject Va. in Figure 4 under three conditions of exposure: (1) wearing the control sateen issue; (2) this issue modified by substituting a zippered front sateen parka and (3) further modified by the wearing of a zippered pile parka in addition to the zipper front sateen parka. Subjective responses of the subject during these three separate exposures to -10°F and a wind velocity of five (5.0) miles per hour are shown below.

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CLOTHING	TIME OF ONSET IN MINUTES		
	Pain in feet	Pain in hands	Shivering
Control Issue	None in 180	None in 180	95
C.I. Modified - Zipper Front Sateen Parka	150	None in 180	145
C.I. Modified - Zipper Front Sateen and Pile Parkas	150	170	95

The predicted equilibrium skin temperatures, θ_e, obtained from the skin temperature curves showed a variation of $\pm 1.5^{\circ}C$. No essential differences in thermal protection were observed between the various modifications of the standard Arctic issue, suggesting that there would be no loss of insulation by the substitution of a front-opening parkas. As will be shown later, the convenience of such garments is a matter of extreme importance.

In a number of experiments the subjects wore two windproof garments, one outside and one inside of the pile garments. No differences were noted in either the subjective responses or the objective measurements made on the subjects at wind velocities greater than zero (0) miles per hour (Table 1). It is interesting to note, however, that under still air conditions the subjective responses of the men were better than when dressed in the control garments. With no wind velocity the phenomena may be similar to that observed when the pile garments of two subjects were soaked overnight in water, and wrung out before being put on. Approximately 2.6 kilograms of water remained in the garments. These two men , one of them being our most susceptible subject, had their most comfortable day. They both remarked about the way the heat remained within the clothes. In both cases the pile garments froze solidly on the outer surface within fifteen minutes. In a few places, such as the groin and axilla no freezing occurred. The prevention of rapid heat exchange between garments was undoubtedly of considerable value in this case. To date this experiment has not been performed in the wind. Whether the benefit achieved will obtain under the conditions of high wind velocities or whether it will fail to be of benefit, as was the case with the double windproof layers, remains to be determined.

In a final experiment to determine the relative importance of leakage of air, all closures on the standard Arctic assembly were made as tight as possible by sewing up openings, by sewing in pieces of similar material at neck, foot, and hand openings (Fig. 2). For extreme comparison, in another test the outer windproof, in an otherwise standard assembly, was torn diagonally for a distance of 18 inches. The mean skin temperatures of a subject dressed in the first experimental assembly (complete closures) are compared with those for the standard combination in Fig. 5 for exposures at $10^{\circ}F$ and 9.6 mph wind. Subjectively this subject was not as well off in the completely closed assembly, since he started to shiver at 45 minutes and had pain in his feet at

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70 minutes. His responses when wearing the standard assembly, on the other hand, were: foot pain at 150 minutes, hand pain at 105 and shivering at 60. Clo values did not differ significantly although the value for the completely closed assembly was slightly higher than that observed for the standard issue (Table 1). In contrast to the foregoing, the comparison between the mean skin temperatures for the torn windproof (Fig. 6) at zero (0) and five (5) mph wind show that adequate closures are important and cannot be neglected. Subjective response and increase in metabolic rate with exposure also indicated the loss of protection resulting from this damage to the windproof garment. These changes occurred, however, only with extreme departure from normal closure design.

It is concluded that present closures are adequate and that no advantage can be gained by further improvement. In this connection, it must be realized that the degree of heat loss that might occur through these avenues, except under extreme conditions of opening, is relatively small compared to the magnitude of heat loss from other areas such as feet, face and hands. Emphasis must be placed upon the need for more quantitative information on the extent of loss from these areas and also on means for minimizing such losses. If improvement in this respect can be accomplished, the relative importance of changes in thermal protection resulting from improved closure design would be more evident.

b. Clothing design in relation to ventilation during work

Although there has been some question regarding the relative value of the closure design on the thermal protection of Arctic zone garments for resting men, there has been little doubt as to the practical inadequacy of the means for ventilation in present garments to compensate for extra heat production during work. It has been suggested that garments be removed as required to prevent excess accumulation of perspiration. This procedure is definitely not one that would be followed by the average soldier. Presence of web equipment hinders easy removal; continued rapid movement despite sweating is frequently necessary; it is commonly impossible to replace removed garments when "pinned" down by enemy action. These are all factors which might lead the solider to refrain from removing his garments during work. A proper solution is evidently some means of ventilating garments without their being removed.

In order to clarify and determine the magnitude of the problem arising from moisture accumulation in Arctic issue clothing during work, a number of tests (67) have been conducted. Three experimental procedures were compared: (1) no ventilation permitted: (2) clothing discarded at will and (3) ventilation as allowed by clothing. The men walked on a motor driven treadmill at three (3) per cent grade and a speed of 3.3 miles per hour. This amount of work involves a caloric expenditure of between 350 and 400 calories per hour. All subjects gained in body temperature, the final average rectal temperature being 100.6°F. There was no significant difference in this respect among the three groups. Figure 7 shows two men working on the treadmill, one with his clothing

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assembly completely closed at all times while the other removed garments as necessary to prevent sweating--a feat which he did not entirely succeed in accomplishing.

Observed weight exchanges are averaged in Table 2 and the data for a single subject appear in Table 3. The weight losses have been corrected for evaporation of water from the lungs and for the difference in the weight of expired carbon dioxide and inspired oxygen. For the rate of work involved, approximately 100 grams per hour is lost through these two sources. The clothing, therefore, appears to have trapped between sixty (60) and ninety (90) per cent of the weight being lost by perspiration.

No distinction is evident between the several clothing issues with regard to their ability to retain or to permit water vapor to pass through them. When men walked with their clothing closed as tightly as possible they lost, on the average, 457 grams per hour (uncorrected) while the clothing showed a gain in weight of 278 grams. The napped Arctic assembly and the assembly with nylon outers appears to be better than the other issues but certain individuals wearing these issues lost as much weight as the average for all clothing assemblies. It is possible that the properties of these fabrics may account for the lower loss and gain in weight but speculation on this matter is not profitable at the present.

A number of experiments were conducted with the standard Arctic assembly ventilated by loosening the tie strings at neck, waist and hips. No appreciable benefit was obtained by this type of ventilation. Tests were then made on the zipper front outer parka with and without zippered pile parkas. Two types of these pile garments were used--one in which the zipper opened the garment from the hem to within a few inches of the neck and the other opening completely from neck to hem (Fig. 3). This last garment fitted too closely around the neck, causing a certain amount of annoyance when worn buttoned and zippered tight.

Some benefit was secured by opening the front fly of the outer parka (Tables 2 and 3). Opening the inner pile garment at the same time was of decided benefit in lessening perspiration and accumulation of water in the clothing. The full opening pile parka was the better of the two types studied. With this combination the average weight loss was 219 grams and the clothing gain 188 grams.

When men are allowed to discard clothing at will, the gain in weight by the clothing is purely a reflection of the man's awareness of his degree of perspiration and warmth. The observation of weight increase in the clothing in this case simply signifies that the man failed to remove clothing fast enough to compensate for added heat production. As a rule, the men stripped down to wool shirt and trousers, starting to remove their two parkas and shell mittens within five minutes of beginning their exercise. By twenty to thirty minutes they had removed two pairs of trousers and opened up their

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wool shirts and the fly of their wool trousers. Most of the men would have removed additional items (Fig. 7) but were afraid that they might get frostbitten if they took off more. The sweating of this group of subjects was significantly diminished as is shown by their reduced weight loss--a forty-five (45) per cent decrease below that experienced by the subjects who removed no clothing.

The explanation of this dramatic decrease in rate and amount of perspiration with the same amount of work output undoubtedly lies in the difference in environmental situations that the two conditions imposed on the man. When clothing is completely closed, the subjects are working in a condition not unlike the low Tropics--a dry bulb temperature of about 33°C and a wet bulb temperature which may be in the upper twenties. When the men shed their clothing on the other hand, their immediate environment approaches a temperate climate and the stimulus to sweating is consequently inhibited.

Since none of the above experiments were conducted with the men wearing equipment of any sort, additional tests were made with two men who wore their web equipment (Table 4). The presence of web equipment does not materially influence the ability to ventilate the zipper front opening Arctic assembly. Perspiration accumulated primarily underneath the web equipment, the underclothing being quite wet in these areas.

An attempt was made to localize the weight gain in the clothing (Table 5). This did not prove to be very satisfactory but the data presented are suggestive. When the sateen windbreak was worn, there was a tendency for water to accumulate in the outermost garments, whereas, with the nylon windbreak more water accumulated in the under garments, close to the skin.

c. Behavior of clothing during resting period after work

Men walked on the treadmill for periods of fifteen minutes to two hours before they sat on the wooden stools. In some instances they were allowed to ventilate their garments as they pleased while in others no ventilation was permitted. The accumulation of some six hundred (600) grams of water in the clothing during a two (2) hour walk did not appear to alter the ability of one resistant subject to sit quietly in comfort for a succeeding period of two and a half ($2\frac{1}{2}$) hours. In general, the only complaint reported by this subject was an initial cooling in the middle of the back during the first few moments after sitting. It is interesting to note, however, that when he put on these damp clothes (especially the socks) for an experiment next morning he reported pain in the toes at 125 minutes, the first and only occasion that he reported discomfort.

The men classed as intermediate or susceptible reported variable responses during their sitting periods following a walk. For example, Subject Ti. on one day sat for slightly over two hours before sensations of discomfort were experienced while on another day he reported extreme discomfort within ninety (90) minutes. As a rule, when seated quietly, this subject reported discomfort before two hours had passed.

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In Figure 8 the mean skin temperatures of a resting subject after working is compared with his thermal experience under the same exposure conditions but without previous activity. It appears that the responses of seated subjects are not appreciably altered by previous moderate activity. A man who has been working and then rests for a short period of time does not seem to have any difficulty as a result of the water accumulated in his garments. However, if he dons damp garments the next day and is forced to sit quietly without preliminary activity, discomfort and probable injury may result.

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TABLE I

COMPARISON OF CLO VALUES (CALCULATED FROM θ_e) OF EXPERIMENTAL GARMENT COMBINATIONS AND THE STANDARD ARCTIC ISSUE

Exposure Temperature - 23.3°C

COMBINATION	CLO OF COMBINATION	CLO OF STD. ARCTIC ISSUE	WIND VELOCITY mph
Sateen windproofs-Parka having zipper front opening	4.9	4.4	5.0
Sateen windproof garment and pile garment, both having full zipper front openings	5.0	4.9	5.0
Sateen garments with all closures closed by sateen material	4.5	4.1	9.6
Two Windproof Garment Layers With Pile Garments Between Them			
Sateen and Herringbone	4.7	4.1	5.0
Sateen and Twill	4.0	5.2	5.0
Sateen and Nylon	4.7	4.6	9.6

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TABLE 2

AVERAGE WEIGHT CHANGES IN MEN AND CLOTHING FOLLOWING ONE-HOUR WALK - 3.3 M.P.H. AND 3% GRADE

Description of Outer Layer	No Ventilation Permitted		Clothing Discarded at Will		Ventilation as Permitted by Garment	
	Wt. Loss Grams*	Cl. Gain Grams	Wt. Loss Grams*	Cl. Gain Grams	Wt. Loss Grams	Cl. Gain Grams
Sateen	449	299	174	102	305	240
Nylons	304	224	-	-	-	-
Herringbone Twill	311	269	-	-	-	-
Cloth, Cotton, Uniform Twill, 8.2 oz	438	263	106	78	-	-
Napped Sateen & Napped Pile	263	234	164	99	-	-
Sateen 9 oz. & 5/8" Pile	467	383	-	-	-	-
Napped Sateen Regular Pile	335	260	-	-	-	-
Sateen 9 oz. with Zipper Front	338	282	170	99	345	255
Sateen 9 oz. with Zipper Front & (S) Pile Parka with Zipper	-	-	-	-	302	255
Sateen 9 oz. with Zipper Front (Open) with Pile Parka (S) Closed with Zipper -	-	-	-	-	283	241
Sateen 9 oz. with Zipper Front & Pile Parka with Zipper	311	284	-	-	219	188

* Corrected for loss through respiration

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TABLE 3

AVERAGE WEIGHT CHANGES IN A SUBJECT AND HIS CLOTHING FOLLOWING ONE-HOUR WALK 3.3 M.P.H. AND 3% GRADE

Description of Outer Layer	No Ventilation Permitted		Clothing Discarded at Will		Ventilation as Permitted by Garment	
	Wt.Loss Grams*	Cl.Gain Grams	Wt.Loss Grams	Cl.Gain Grams	Wt.Loss Grams	Cl.Gain Grams
Sateen	340	241	178	104	310	225
Nylons	316	224	-	-	-	-
Herringbone Twill	311	269	-	-	-	-
Cloth,Cotton,Uniform Twill 8.2 oz	481	263	106	78	-	-
Napped Sateen & Napped Pile	384	234	262	99	-	-
Sateen 9 oz. and 5/8" Pile	467	383	-	-	-	-
Napped Sateen Regular Pile	335	260	-	-	-	-
Sateen 9 oz. with Zipper Front	375	282	170	99	297	184
Sateen 9 oz. with Zipper Front & (S) Pile Parka With Zipper	-	-	-	-	156	127
Sateen 9 oz. with Zipper Front (Open) With Pile Parka (S) Closed With Zipper	-	-	-	-	214	191
Sateen 9 oz. With Zipper Front & Pile Parka with Zipper	311	284	-	-	113	71

* Corrected for loss through respiration

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TABLE 4

INFLUENCE OF WEARING WEB EQUIPMENT* ON WEIGHT CHANGES FOLLOWING ONE HOUR WALK

	Condition of Test	Weight Loss Man Gm.	Weight Gain Clothing Gm.	Final Rectal Temp.	Rectal Temp.
SUBJECT E					
Sateen Windbreak with Zipper and Pile Parka with Zipper	Ventilated	360	241	100.8	0.9
	Ventilated-webbing	397	225	100.6	1.2
SUBJECT H					
Sateen Windbreak with Zipper and Pile Parka with Zipper	Closed	447	270	100.6	1.7
	Closed - webbing	425	284	100.9	1.6

*Pistol Belt, Musette Bag, and Gas Mask

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TABLE 5

WEIGHT CHANGES IN SEPARATE ITEMS OF ARCTIC ISSUE
FOLLOWING A ONE HOUR WALK WITHOUT VENTILATION

ITEM OF ARCTIC ISSUE	Sateen Windbreak				Nylon Windbreak			
	Subject H		Subject G		Subject H		Subject G	
	Initial Wt. GM	Wt. Change GM	Initial Wt. GM	Wt. Change GM	Initial Wt. GM	Wt. Change GM	Initial Wt. GM	Wt. Change GM
Complete Issue	8250	+ 326	8675	+ 184	7428	+ 212	7347	+ 227
Socks, Wool	383	+ 28	439	0.0	383	+ 28	387	+ 14
Shoes, Arctic Felt	1389	+ 47	1304	+ 28	1432	- 28	1281	+ 28
Underwear, Wool 50/50	638	+ 43	1784	- 14	553	+ 113	680	+ 33
Trousers, Field Wood, O.D.	936	+ 43	1021	+ 43	964	- 14	978	+ 19
Shirt, Flannel O.D.	496	+ 14	482	+ 28	496	+ 14	468	+ 28
Trousers, Field Pile	936	0.0	978	+ 14	950	+ 43	916	+ 28
Trousers, Field O.D.	695	- 14	737	0.0	354	- 14	378	+ 5
Parka, Pile	1233	+ 57	1361	+ 43	1247	+ 57	1313	+ 33
Parka, Field, O.D.	992	+ 71	1006	+ 28	482	0.0	416	+ 14
Mittens and Wristlets	383	+ 14	369	+ 14	369	+ 14	359	+ 14
Muffler, Wool	170	+ 14	184	0.0	184	0.0	170	+ 9
Subject (Nude)		- 539		- 510		- 369		- 416

Incl # 2

THE FRONT OPENING ZIPPER WINDPROOF PARKA (9 OZ. SATEEN) AND THE SIDE-FRONT-OPENING PILE PARKA COMPARED WITH A CLOSED WINDPROOF PARKA.

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Fig. 1

A 9 OZ. SATEEN WINDBREAK WITH ALL OPENINGS CLOSED.

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Fig. 2

TYPES OF PILE PARKAS USED DURING TEST

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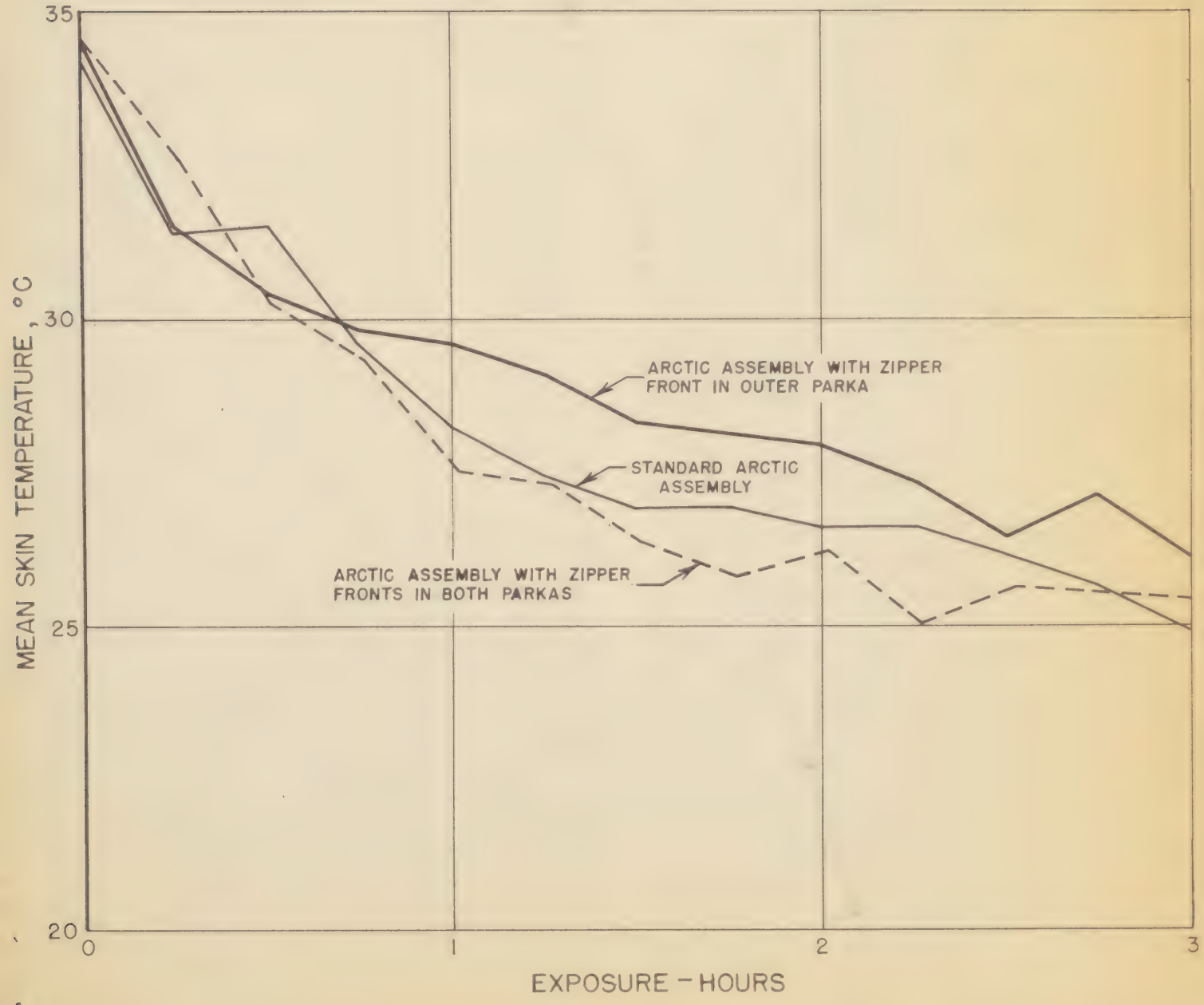
Fig. 3

FIG. 4

MEAN SKIN TEMPERATURES FOR DIFFERENT DEGREES OF GARMENT CLOSURE

AMBIENT TEMPERATURE = -10° F ; 5 MPH WIND

SUBJECT VA



Incl # 3

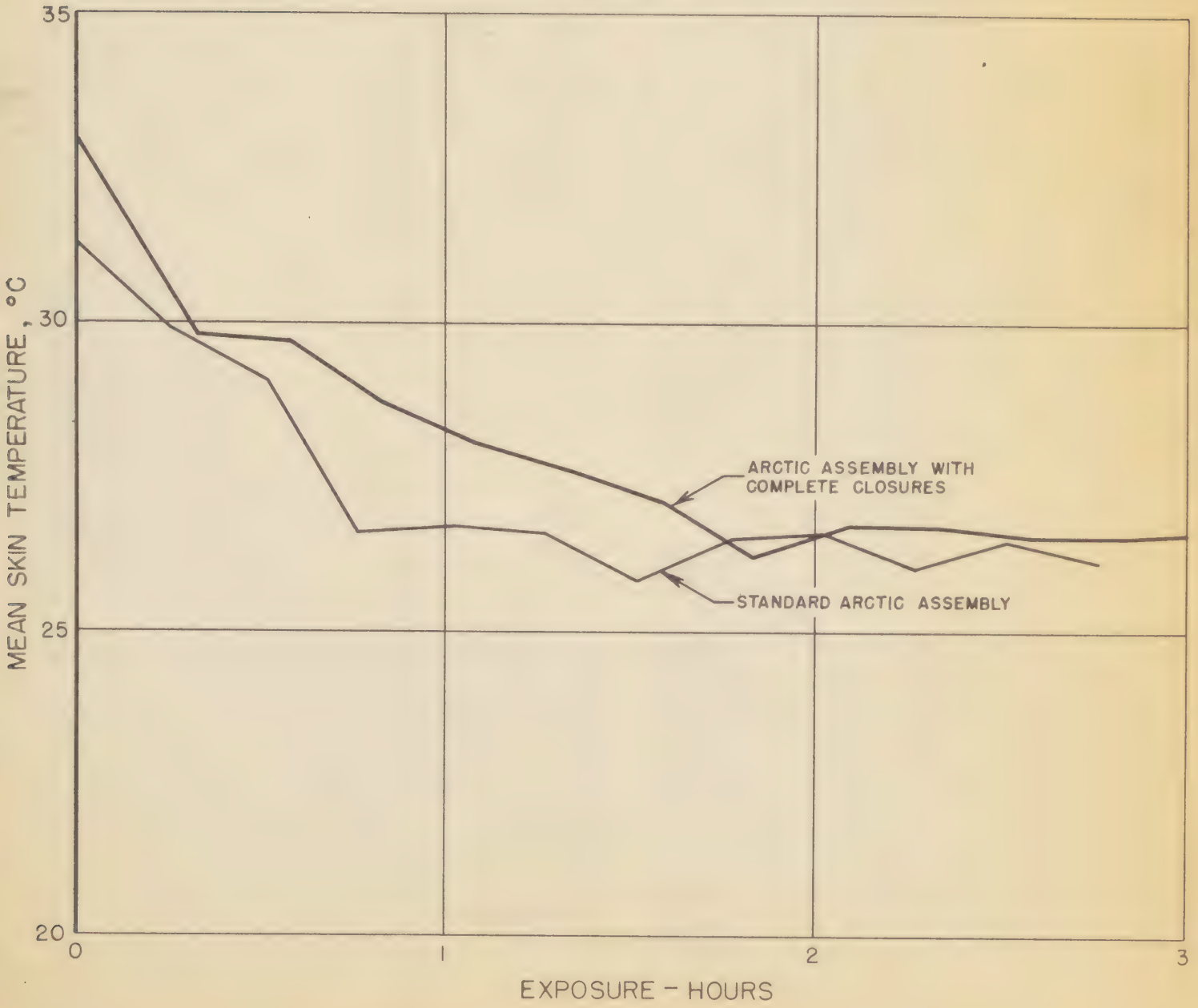
FIG. 4

FIG. 5

MEAN SKIN TEMPERATURES FOR STANDARD ARCTIC ASSEMBLY COMPARED WITH FULLY CLOSED ASSEMBLY

AMBIENT TEMPERATURE = -10° F ; 9.6 MPH WIND

SUBJECT BA



Trial #3

FIG. 5

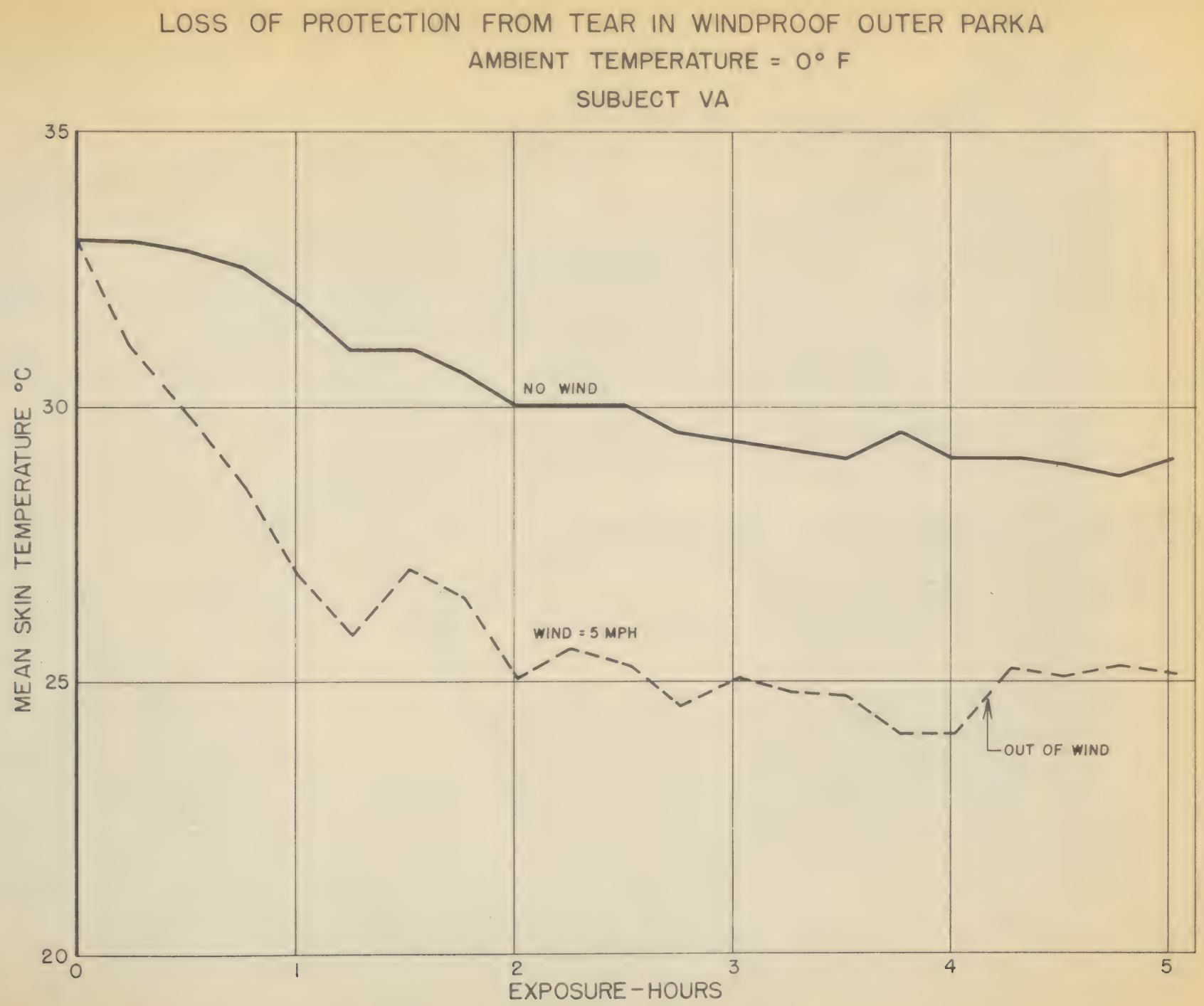


FIG. 6

FIG. 6

Anal #3

MEN WALKING ON TREADMILL AT -10°F.
ONE MAN DISCARDED AT WILL, OTHER MEN WORE GARMENTS CLOSED.

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Project 20-1 Fig. 7

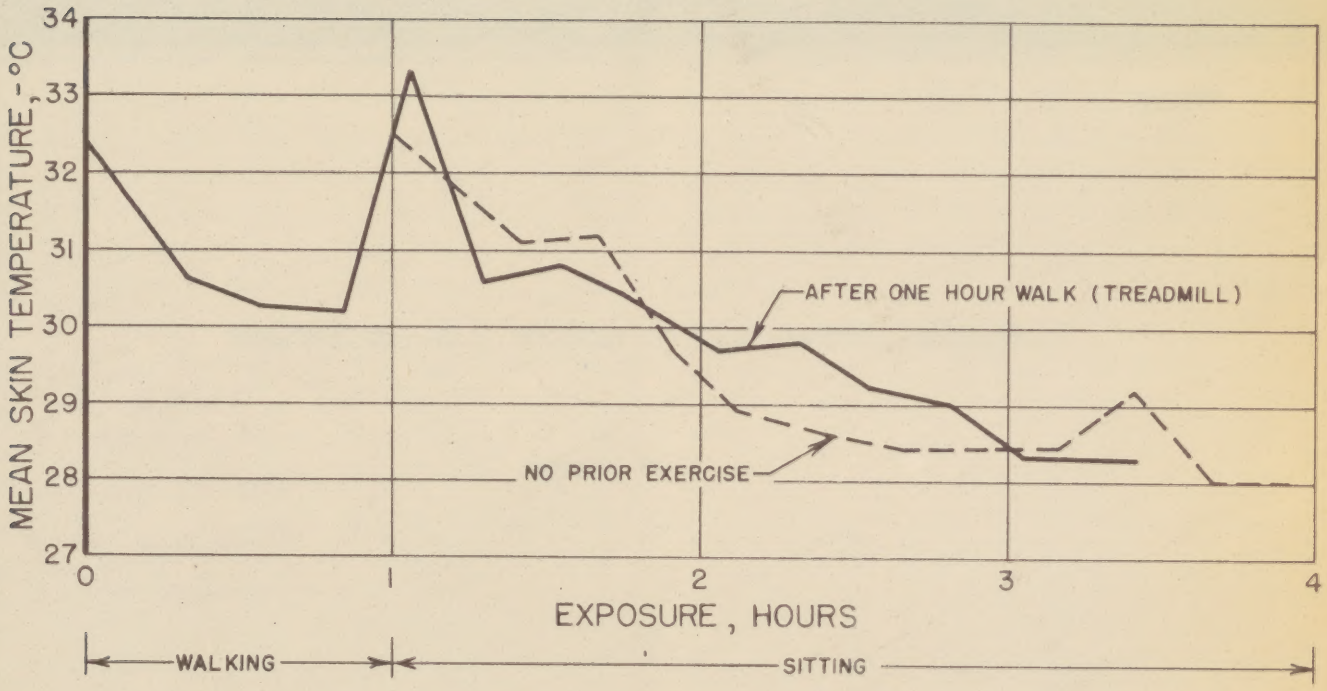
FIG. 8

EFFECT OF EXERCISE UPON MEAN SKIN TEMPERATURE DURING SUBSEQUENT REST IN COLD

SUBJECT CH

AMBIENT TEMP. = -10° F; 5 MPH WIND

(STANDARD ARCTIC ASSEMBLY)



Incl # 3

FIG. 8